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BULLETIN NO. 321

(RESEARCH BULLETIN)

EFFECT OF HYDROGEN-ION CONCENTRATION ON THE GROWTH OF STRAWBERRIES IN SAND AND IN SOIL.

Lexington, Ky.

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(331)

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SUMMARY

A variety of everbearing strawberries was grown in sand and in soil, in the greenhouse. The reactions of the cultures were maintained artificially over a range of pH 3 to pH 9, at intervals of 1 pH. The effect of reaction on plant growth, fruiting, and the chemical composition of plants and sand was studied. The data obtained may be summarized as follows:

1. The plants grew best at a reaction of about pH 5.3 to pH 5.5.

2. A reaction of pH 3 or of pH 9 was prohibitive to growth.

3. Extreme acidity was more quickly toxic than extreme alkalinity.

4. A reaction that was most favorable for growth also induced greatest fruitfulness.

5. The chemical composition of the plants was influenced materially by the reaction of the medium in which they grew.

6. It seems probable that enough lime can be added to the soil to promote the growth of clover without making the reaction too alkaline for the growth of strawberries subsequently.

BULLETIN NO. 321

(RESEARCH BULLETIN)

Effect of Hydrogen-Ion Concentration on the Growth of Strawberries in Sand and in Soil.

By C. S. WALTMAN*

That strawberries require an acid soil and that lime applied to the soil in which plants are to be set is likely to be injurious is a common belief. If the soil is not very acid, liming probably would be harmful to strawberries which are to be planted immediately. But leguminous crops, especially clover, that can be turned under in the fall previous to setting strawberry plants in the spring, are valuable in preparing the land for a new bed. As clover requires lime for its best growth, the strawberry grower is confronted with the problem of whether he can use lime to aid the growth of clover and yet not impair the growth of strawberry plants subsequently planted on the same land.

A review of the literature available seems to show that strawberries require a slightly acid soil and that both alkalinity and strong acidity are harmful. Hartwell and Damon (2) found lime beneficial to strawberries in an acid soil that had been fertilized with sulfate of ammonia, but the gain from lime where nitrate of soda had been used was very small. Wright (6) found that liming strawberries, even on an acid soil, was harmful, and Darrow (1) states that lime has a harmful effect upon the roots of strawberries. Morris and Crist (5) observed wild and cultivated strawberries growing vigorously on acid, neutral, and alkaline soils. In most instances, however, the soil was acid.

* The writer desires to express his appreciation of the assistance rendered in the preparation of this manuscript, to Professors A. J. Olney and P. E. Karraker, for valuable suggestions and criticisms in planning the work. To Dr. A. M. Peter for helpful suggestions in the preparation of the manuscript, and to Dr. E. M. Emmert for cooperation and advice in the chemical analyses.

Growth in water cultures was very satisfactory within the range of pH 4 to pH 8. The optimum reaction was pH 5.7 to 6.

In this work it was proposed to determine the effect of hydrogen-ion concentration on the growth of strawberry plants, in sand, with a nutrient solution, and in soil. Three experiments were carried out. In the first two, strawberry plants were grown in sand to which was added a basal nutrient solution, modified by the addition of enough glacial acetic acid or sodium hydroxide solution to produce the desired pH. In the third, strawberry plants were grown in greenhouse soil in which the desired reaction was maintained by the addition of calcium hydroxide or phosphoric acid. The factors other than hydrogen- and hydroxyl-ion concentration were made identical insofar as possible.

THE APPARATUS FOR SAND CULTURES

A modification of the apparatus suggested by McCall (3) was used. Ordinary acid bottles with bottoms removed served as percolator jars. These were covered with black paper and placed in frames in an inverted position. The equipment consisted of twenty-one bottles, divided into seven groups of three each. Each group represented a definite degree of hydrogen-ion concentration, from pH 3 to pH 9, inclusive. The jars were arranged in such a way that no frame carried two containers of the same reaction. Their arrangement is shown in Figure 1.

THE MEDIUM

A fine grade of white glass sand was obtained from West Virginia.* The sand was washed thoroly with tap water and then with distilled water and dried. Each percolator jar received 3200 grams of dry sand.

THE NUTRIENT SOLUTION

At the time this project was outlined it was difficult to find a well-buffered nutrient solution that was recognized as favor-

* The chemical analysis of the sand was as follows:

Silica (SiO_2)	99.580
Ferric oxide (Fe_2O_3)	0.068
Aluminum oxide (Al_2O_3)	0.199

able to the growth of strawberries in sand cultures. The following solution suggested by M. B. Davis, Central Experimental Farm, Ottowa, Canada, was used in the sand cultures after several others had been found unsatisfactory.

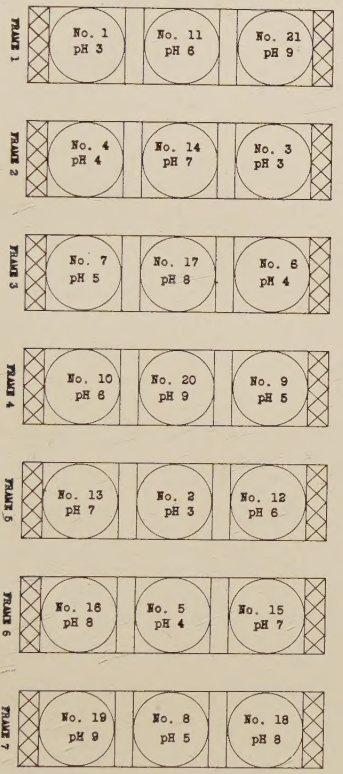

Fig. 1. Arrangement of Bottles in Frames.

When NaOH was added to the nutrient solution, precipitation of calcium and magnesium compounds occurred at all reactions above pH 6. The precipitation at pH 6 was only a slight cloudiness. It was heavier at pH 7 and 8, and very heavy at pH 9. The precipitation of phosphates of calcium and magnesium is a characteristic reaction above pH 6.

Iron was supplied to all solutions by the use of 0.5 percent

solutions of ferric tartrate and ferric citrate. One c. c. of each per liter was used alternately in the solutions at the time they were made up. In addition to the iron supplied in the solution,

Material	Grams per liter	Elements. Parts per million
$MgSO_4 7H_2O$	0.1440	14 pts. Mg 18 pts. S
KH_2PO_4	0.1550	33 pts. K 26 pts. P
KCl	0.0320	17 pts. K 15 pts. Cl
$CaCl_2H_2O$	0.2694	84 pts. Ca 148 pts. Cl
NH_4NO_3	0.6905	242 pts. N

the leaves of plants growing at reactions above pH 6 were painted with a .05 percent ferric chloride solution, when their appearance seemed to indicate the need for it. (4)

RENEWING THE SOLUTIONS

When it was desired to renew the solutions, each percolator jar was weighed and the amount of solution still remaining in it was calculated from the previous weighing. Suction was then applied and the solution drawn into a graduated bottle. The first 100 c. c. was discarded and the next 300 c. c. used for making pH determinations. Six hundred and forty cubic centimeters of solution, or 20 percent of the weight of the sand, was used in each jar, at the time of each change.

All pH determinations were made by means of a quinhydrone electrode. This apparatus was checked frequently with a standard buffer solution.

SELECTION OF PLANTS

New runner plants of the Mastodon Everbearing variety were used. For the first sand-culture experiment, runners were set in five-inch pots of sand soon after they were formed. As

soon as the roots were started, the runner was severed from the parent plant. Later work indicated that the runner should remain attached until the new plant becomes established. Davis of Ottawa reported similar results. For the other experiments, plants were selected from the field and set in clean sand for a few days before being transferred to the cultures.

SAND-CULTURE EXPERIMENT NO. 1

The plants in the first experiment were weighed and placed in the sand May 24, 1929. For the following ten days all jars were treated uniformly with a complete nutrient solution, at pH 6. This was done so that all plants would be given the same chance to start growth before being subjected to nutrient solutions of different hydrogen- and hydroxyl-ion concentrations. The treatment with the nutrient solutions of the desired reactions was started on June 2 and continued for about eight weeks. Complete removal and renewal of solutions in the containers was made every third day and on the days when the solutions were not changed, 150 c. c. was added to each container.

SAND-CULTURE EXPERIMENT NO. 2

Experiment 2 was a repetition of Experiment 1 with a few changes in technique. The plants were set in the jars January 9, 1930, and the work was completed March 19. The same variety was used. In this experiment the sand was treated with the nutrient solution of the desired pH until the proper reaction was established before the plants were set. Complete changes of the solutions were made more frequently than in Experiment 1. The amounts of solution used at each change were the same as before. For about four weeks, the solutions were renewed every other day, and during the last half of the experiment the solutions at pH 6, 7 and 8 were renewed daily.

SOIL-CULTURE EXPERIMENT

Experiment 3 was a soil culture in which the reaction was maintained artificially. It seemed reasonable to expect that under soil conditions the response made by strawberries to acid

and alkaline reactions might be different from that in sand. Good garden soil to which compost had been added was used and a range of reaction from pH 3 to pH 9 was obtained by the use of phosphoric acid or calcium hydroxide. The plots, 20 x 39 inches, were arranged in a greenhouse bench. Eight plants of the Mastodon variety were set in each plot and two untreated check plots were included in the series. The reaction was established before the plants were set. The soil treatments were started December 15, 1929, and the plants set December 29.

PLANT GROWTH AND FRUIT PRODUCTION

In sand-culture experiment 1, twenty-four hours after treatment with the solution at pH 3, the plants in Jars 1, 2, and 3 showed blackened areas immediately surrounding the veins of the leaves. On June 9 these plants were dead. On June 7 plants in Jars 19 and 20 which had received a solution at pH 9 were severely wilted, but there was no blackening of the leaves.

TABLE 1. GAIN IN WEIGHT, FRUIT PRODUCTION AND GENERAL CONDITION OF PLANTS. EXPERIMENT 1.

pH Value	Pot No.	Total Gain, Green Wt. of Plants (grams)	Wt. of Fruit (grams)	Condition of Tops
	1	—	—	Dead June 7.
3	2	—	—	Dead June 7.
	3	—	—	Dead June 9.
	4	—	4.1	Dead July 10.
4	5	5.6	11.2	Weak growth. Few small leaves.
	6	2.8	7.0	Poor growth. Leaves small.
	7	24.2	27.1	Large leaf area. Plants vigorous.
5	8	25.2	36.7	Excellent growth. Leaves large, dark green.
	9	22.5	25.6	Growth similar to Nos. 7 and 8.
	10	27.0	31.6	Excellent growth. Large, dark-green leaves.
6	11	5.1	21.3	Weak growth. Plant did poorly.
	12	13.4	22.7	Fair growth. Younger leaves chlorotic.
	13	6.1	9.7	Chlorotic condition. Leaves variable.
7	14	13.0	11.5	Few large leaves. Growth rather poor.
	15	18.0	25.1	Good growth. Young leaves chlorotic.
	16	5.3	6.6	Weak growth. Leaves light green.
8	17	11.1	17.6	Weak plant. Poor color.
	18	9.3	18.1	Chlorotic leaves. Growth poor.
	19	—	—	Dead June 12.
9	20	—	—	Dead June 12.
	21	—	—	Dead June 16.

These two plants were dead on June 12. Plant No. 21 of the series died June 16. The gain in weight and general condition of the plants and their fruit production, are given in Table 1. The comparative growth of the plants, and their fruit production are shown in Figure 2.

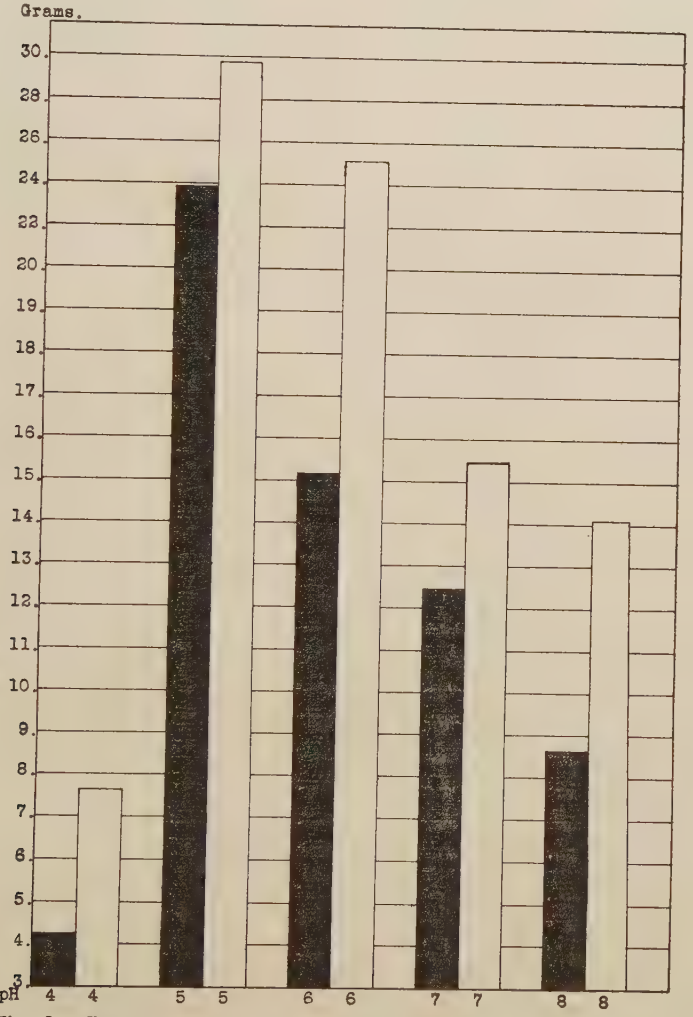

Fig. 2. Comparative Growth of Plants and Yields of Fruit, at Different pH values. The shaded areas represent plant growth, the unshaded, fruit production.

In sand-culture Experiment 2, all plants which had been subjected to the solution at pH 3 died within twelve days, and those treated with the solution at pH 9 died a few days later. The appearance of these plants was identical with that of the corresponding plants in Experiment 1. Similarly, with the

TABLE 2. GAIN IN WEIGHT, AND GENERAL CONDITION OF PLANTS. EXPERIMENT 2.

pH Value	Pot No.	Total Gain, Green Wt. of Plants (Grams)	Condition of Tops	Condition of Roots When Removed
3	1	—	Dead Jan. 20.	
	2	—	Dead Jan. 21.	
	3	—	Dead Jan. 17.	
	4	.8	Poor growth. Leaves small, light color.	Few new, short roots.
4	5	—	——	——
	6	.8	Poor growth. Leaves small, light color.	2-5 cm. long. Few new roots.
	7	14.2	Fairly healthy plant. Leaves normal.	Many fibrous roots.
5	8	22.4	Good growth. Large dark-green leaves.	Excellent root system. Many lateral roots 7-18 cm.
	9	18.3	Good growth. Leaves normal size and color.	Vigorous roots. Well-developed laterals, 5-14 cm.
	10	20.2	Normal plant. Good growth and color.	Many new roots, somewhat smaller than 7, 8 or 9.
6	11	5.0	Growth restricted. Younger leaves chlorotic.	Rather poorly developed. Few fibrous roots, 3-8 cm.
	12	8.2	Fair growth. Younger leaves slightly chlorotic.	Fair root development. Several new laterals.
	13	3.0	Poor growth. Leaves small, crown leaves chlorotic.	Few new roots, dark brown. Fibrous roots poor.
7	14	12.2	Good growth at first. All leaves light green.	Several new roots. Fair development, 6-12 cm.
	15	1.1	Poor growth. Younger leaves chlorotic.	Few new roots. Dark-brown. Poor laterals.
	16	—	Dead Feb. 22.	——
8	17	—	Dead Feb. 25.	——
	18	3.3 removed	Plant dying when removed.	No new roots, all very brown.
	19	—	Dead Feb. 2.	——
9	20	—	Dead Feb. 2.	——
	21	—	Dead Feb. 22.	——

plants that survived, best growth was on the acid side at a pH between 5 and 6. Increasing acidity to a point considerably below the optimum killed the plants more quickly than increasing the alkalinity to a point considerably above the optimum. The plants at pH 4 made little growth and were inferior to those at pH 8.

The plants in this experiment failed to produce fruit. A few blossoms opened, but all were abnormal. In many, petals were almost entirely lacking and in most, the stamens were poorly developed. In neither the first nor second sand experiment was there any indication of runner growth. The gain in weight and condition of plants in Experiment 2 are given in Table 2.

In the soil cultures, Experiment 3, sixteen plants, or two complete lots, died at the pH 3 reaction. Six plants died at pH 4 and seven at pH 9. The mortality of plants in this experiment was strikingly similar to that in the sand cultures. Plants did not grow at either pH 3 or pH 9, and were injured more quickly by extreme acidity than by extreme alkalinity. Toxic action was slower in soil than in sand cultures. Fruit production from the soil plots is presented in Table 3. Practically no runners were formed from the plants in this experiment.

TABLE 3. FRUIT PRODUCTION FROM THE SOIL PLOTS.

Plot No.	pH of Soil	Fruit Harvested April 28 to July 10			Plant Mortality June 28
		No. Fruits	Total Wt. (grams)	Ave. Wt. (grams)	
1 Ck	6.83	77	263.2	3.4	0
2	3.27	0	—	—	16 (2 lots)
3	4.15	13	39.4	3.0	5
4	5.01	114	513.9	4.5	1
5	6.30	103	439.4	4.3	1
6	7.38	84	350.5	4.2	2
7	8.08	46	226.3	4.9	4
8	8.76	1	2.5	2.5	8
9 Ck	6.93	72	309.9	4.3	0

MAINTAINING REACTION IN THE SAND CULTURES

The findings for pH in the solution drawn off from the cultures in Experiment 1 are not included in this paper. They appeared to indicate that the cultures to which sodium

hydroxide solution had been added were not maintained at the desired reaction. The pH 9 jars were an exception. These were held more closely to the point desired than were any others of the experiment. There was evidence of a definite relationship

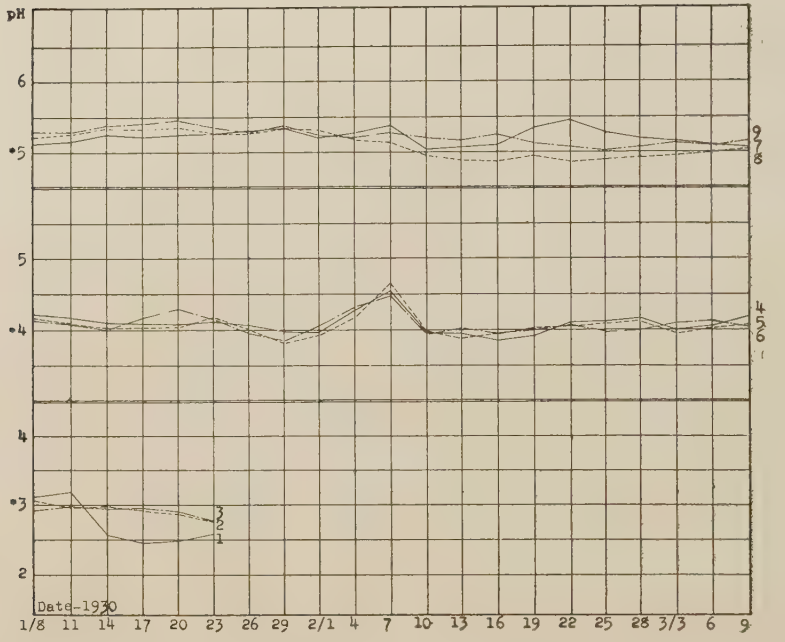

Figure 3. H-ion concentration of the solutions drawn off from the jars, Experiment 2. Desired pH 3, 4 and 5. The figure at the end of each line is the number of the jar.

between the growth of the plants and the pH of the solution added. This led the author to believe that determination of the pH of the solution removed from the jar was not an accurate measure of the reaction to which the plants had been subjected. The findings for pH in the solutions drawn off from the jars in Experiment 2 are given in Figures 3, 4 and 5. These results are nearly identical with those from Experiment 1.

Where acetic acid was used to obtain the desired reaction, little difficulty was experienced in maintaining the same reaction in the sand. The sodium hydroxide used to establish

all reactions above pH 5 apparently reacted with the sand and the solutions removed usually showed an acid reaction. This was true in all except the cultures that received a pH 9 solution and jar No. 18. The sand in Jar 18 was not used in Experiment 1 and consequently had received fewer treatments of the alkaline nutrient solution. It will be noted, however, that as the experiment progressed the solution drawn off gradually became less alkaline.

One week before this experiment was finished and again immediately after the plants were removed, pH determinations were made directly on the sand in which the plants had been growing. The results are recorded in Table 4.

TABLE 4. pH DETERMINATIONS ON THE SAND AND ON THE SOLUTIONS DRAWN OFF FROM CULTURE JARS.

pH of Solution Added	Jar No.	pH of Sand*	Ave. pH of Solutions Drawn Off**
4.	4	4.14	4.08
	5	4.08	4.08
	6	4.00	4.07
5.	7	5.26	5.21
	8	5.14	5.10
	9	5.16	5.22
6.	10	5.88	5.42
	11	6.09	5.54
	12	6.29	5.62
7.	13	6.77	6.16
	14	6.70	6.21
	15	6.50	5.74
8.	16	7.76	6.57
	17	7.83	7.14
	18	7.97	7.99

* Average of two determinations.
** Average of 21 determinations.

The findings show that the reaction of the sand was nearer the point desired than was indicated by the determinations made on the solutions which were removed from the containers. Apparently a chemical reaction took place between the sodium hydroxide in the alkaline solutions and the sand. To further test this point two jars of sand were used and a nutrient solution of pH 8, identical with that used with the plants, was added to each. No plants were set in the jars. One jar of sand was

No. 16 which had just previously been used in Experiment 2. It had received a pH 8 solution thruout the course of Experiment 2. The dead plant was removed from the jar but the sand was not rewashed before the test was started. The other jar,

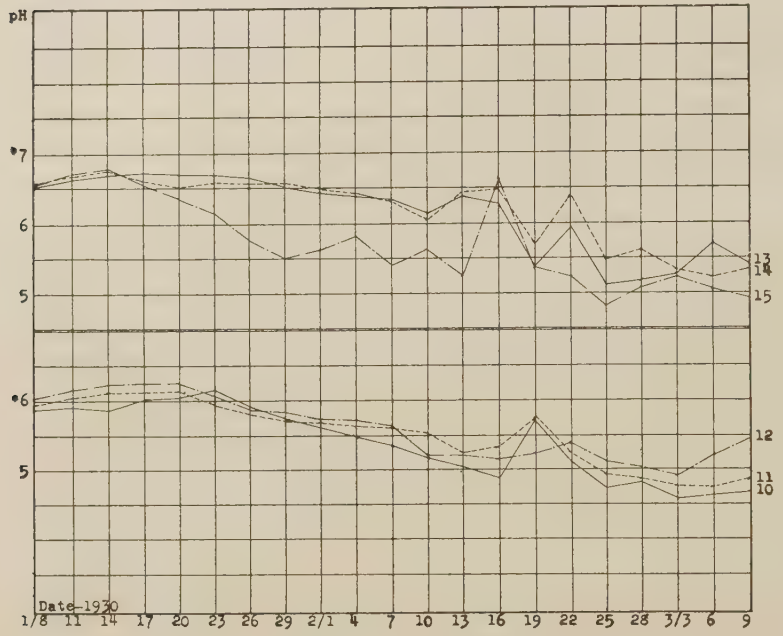

Figure 4. H-ion concentration of the solutions drawn off from the jars, Experiment 2. Desired pH 6 and 7. The figure at the end of each line is the number of the jar.

No. 16-A, contained a quantity of the same lot of sand which had been acid washed. No plant had been grown in it and no nutrient solution had been added previously. Renewals of the solution and pH determinations were made the same as in the previous work. The results of this test are given in Table 5.

The data of Table 5 indicate that there was a reaction between the sodium hydroxide in the nutrient solution and the sand. In searching for probable explanations of why a solution containing sodium hydroxide should change in reaction so rapidly when added to and then removed from sand cultures, as

was shown by figure 5, there seem to be four possibilities: absorption of sodium hydroxide by sand; chemical reaction between sodium hydroxide and sand; bacterial activity, and the action of carbon dioxide. With sand previously untreated the reaction proceeded slowly. The data recorded from jar 16-A, in Table 5 show the tendency for the solution in contact with the sand to change gradually toward a more acid condition, while the readings from the sand show a gradually decreasing acidity. Chemical reaction between the solution and the sand presumably would become gradually less until the sand had taken up all the sodium possible. Bacterial activity in the cultures, should increase with lapse of time until a maximum is reached. This maximum might be maintained as long as the food supply of the bacteria was sufficient and the reaction in the sand favorable. With sand in which plants are growing, the

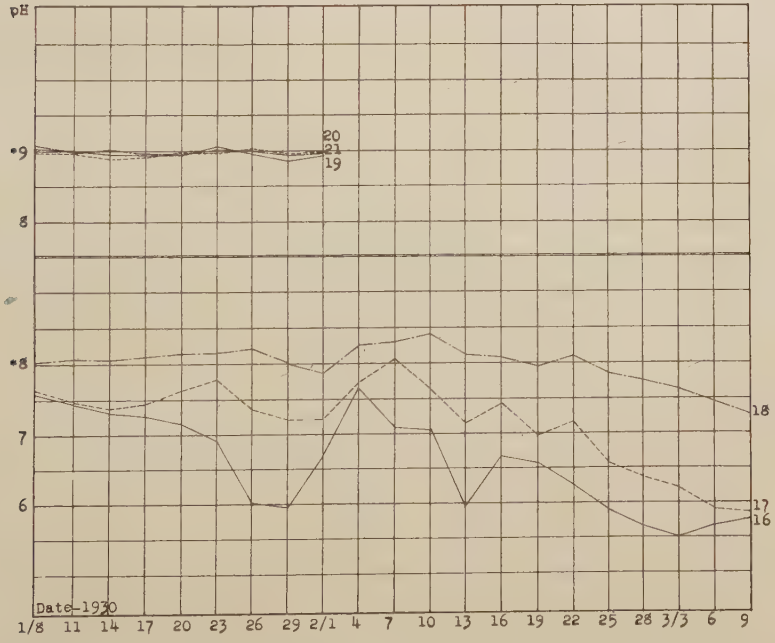

Figure 5. H-ion concentration of the solutions drawn off from the jars, Experiment 2. Desired pH 8 and 9. The figure at the end of each line is the number of the jar.

change in reaction of the nutrient solution might be accounted for in part by the effect that the plants have in changing the reaction toward neutrality. However, in the experiment reported in Table 5, no plants were growing in the sand.

TABLE 5. REACTION OF THE SAND AND OF THE SOLUTION REMOVED.

Date Read	Pot No.	pH of Solution Added	pH of Solution Removed	pH of Sand	No. of Readings Averaged
Apr. 15	16	8.26	5.11	7.93	4
Apr. 16	16	8.26	5.52	8.02	5
Apr. 16	16-A	8.26	6.65	6.68	6
Apr. 17	16-A	8.26	6.57	6.89	5
Apr. 18	16-A	8.26	6.42	6.97	5
Apr. 21	16-A	8.26	5.87	7.12	4

CHEMICAL COMPOSITION OF PLANTS AND SAND

At the conclusion of Experiment 2, the leaves, crowns, roots and sand were analyzed to determine their content of total nitrogen, nitrate nitrogen, total phosphorus, and phosphate phosphorus. The results are presented in Tables 6 and 7.

Uniform samples of crowns and roots were difficult to obtain, which may explain the lack of uniformity in the results. However, there appeared to be a tendency toward storage of total nitrogen in the crowns, at the reaction at which the plants grew best. At pH 5 and 6 the concentration of nitrogen was greater in the crowns than in the leaves, roots or sand, but at pH 7 and 8, the leaves contained a larger proportion of nitrogen than the sand.

A definite relationship is shown between the total nitrogen and nitrate nitrogen content of leaves and sand and the green weight increase of the plants. At pH 4, 7 and 8 the content of nitrogen in the sand is larger than at either pH 5 or 6, presumably because growth at the former reactions was less and the plants did not use the nitrogen. The amount of nitrate nitrogen at pH 5 and 6 corresponds closely to the content of this material in field soils on which plants make good growth; namely, 20-30 parts per million.

The differences in the amounts of total phosphorus and water soluble phosphorus in the sand are similar to those of nitrogen. At pH 4, where plant growth was poor, the phosphorus was undoubtedly carried out in the liquid that was removed by suction. The plants growing at pH 5 and 6 had well-developed roots. This seems to indicate that these reactions

TABLE 6. NITROGEN CONTENT OF PLANTS AND SAND. EXPERIMENT 2.

pH Value	Pot No.	Total Nitrogen				Nitrate Nitrogen			
		Leaves Percent	Crowns Percent	Roots Percent	Sand P.P.M.	Leaves Percent	Crowns Percent	Roots Percent	Sand P.P.M.
4	4	.67	.88	—	213	—	.014	—	42
4	5	—	—	—	213	—	—	—	43
4	6	.68	1.40	—	138	—	—	—	21
5	7	.76	1.12	.22	60	.033	.018	.025	25
5	8	.76	1.12	.22	60	.053	.012	.035	26
5	9	.77	.88	.26	60	.041	.012	.030	30
6	10	.47	.80	.26	60	.033	.019	.032	19
6	11	.45	1.20	.38	60	.035	.011	.033	20
6	12	.43	—	.28	60	.033	.011	.025	20
7	13	1.78	—	—	47	.055	.008	.030	28
7	14	1.72	.64	.28	67	.045	.018	.035	34
7	15	1.78	.88	—	57	.058	.019	—	26
8	16	—	—	—	100	—	—	—	35
8	17	—	—	—	85	—	—	—	40
8	18	2.06	.88	—	70	.180	—	—	35

TABLE 7. PHOSPHORUS CONTENT OF PLANTS AND SAND. EXPERIMENT 2.

pH Value	Pot No.	Total Phosphorus				Phosphate Phosphorus		Water Soluble Phosphorus
		Leaves Percent	Crowns Percent	Roots Percent	Sand P.P.M.	Leaves Percent	Roots Percent	Sand P.P.M.
4	4	.20	.17	—	30	—	—	11
4	5	—	—	—	40	—	—	14
4	6	.20	.19	—	38	—	—	8
5	7	.10	.16	.032	24	.053	.027	9
5	9	.10	.07	.032	34	.039	.038	8
6	10	.13	.10	.035	36	.050	.035	15
6	11	.15	.23	.048	28	—	.021	8
6	12	.14	—	.049	38	.051	.050	17
7	13	.21	—	—	30	—	—	10
7	14	.13	.12	.048	25	.038	.041	31
7	15	.22	.18	—	120	—	.048	36
8	16	—	—	—	720	—	—	68
8	17	—	—	—	500	—	—	66
8	18	.23	.14	—	120	—	—	62

were favorable to the utilization of phosphorus. The larger phosphorus content of the sand at pH 8 undoubtedly was due to a reaction between the phosphate and calcium ions in the alkaline solution, to form insoluble tricalcium phosphate, and

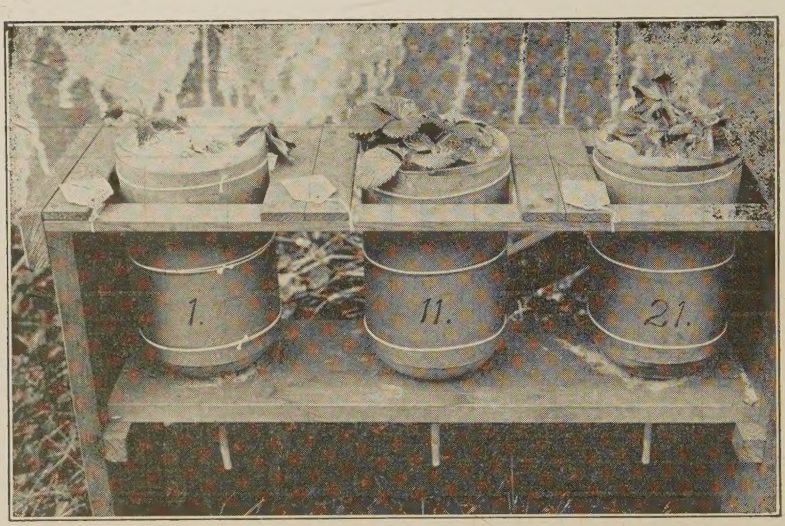

Figure 6. Comparative growth of plants at pH 3, 6 and 9. Experiment 1.

this prevented loss by drainage. Either the insolubility of the phosphorus compounds or the toxicity of sodium hydroxide may have been contributing factors to the poor growth of plants at this reaction. Certainly nitrate nitrogen was not a limiting factor to growth at pH 8.

DISCUSSION AND CONCLUSIONS

The response made by strawberries growing in soil in which the reaction was artificially maintained, was very similar to that of those growing in sand. Because of the buffer action of the soil, the toxicity of extreme acidity or alkalinity was less pronounced and the action slower than in sand. Acidity at pH 4 was more toxic to plants than alkalinity at pH 8. At the latter reaction, however, the plants gradually became weakened and finaly died. In all experiments growth was better and fruit

production greater at acid than at alkaline reactions. A hydrogen ion concentration of pH 5.3 to 5.5 appeared to be most favorable. Morris and Crist found growth in water cultures very satisfactory within the range of 5 to 7. The optimum reaction was 5.7 to 6..

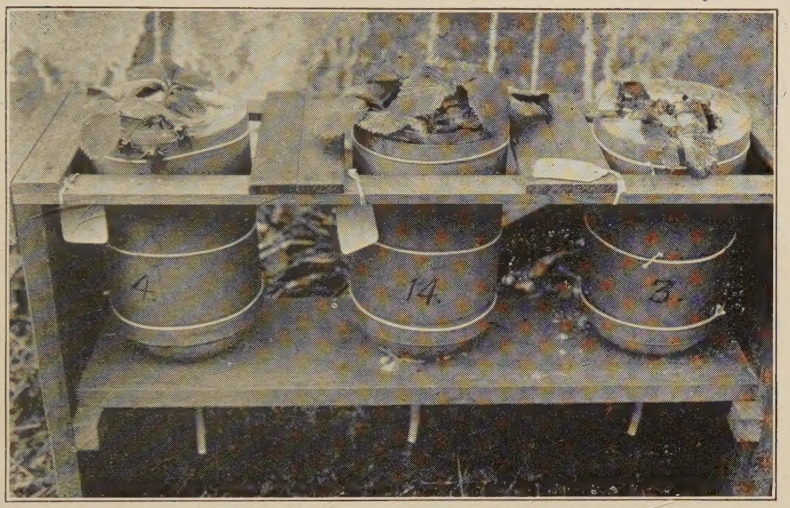

Figure 7. Comparative growth of plants at pH 4, 7 and 3. Experiment 1.

The results appear to indicate that strawberries need a relatively large amount of phosphorus and that the reaction of the soil may influence materially the availability of this substance. It appears that an acid reaction is favorable to the utilization of phosphorus by the plants.

The data from these experiments do not seem to justify the application of lime to land just before strawberry plants are to be set. In fact, the results indicate that liming may be harmful unless the initial reaction of the soil is so acid that plants cannot grow. It seems probable that lime may be added to soil in quantity sufficient to benefit the growth of clover and yet not change the reaction of the soil to a point that would be injurious to strawberries.

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